Radar Data Quality Control and Assimilation at the National Weather Radar Testbed (NWRT)

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LONG-TERM GOALS

Study and develop advanced approaches for radar data quality control (QC) and assimilation that will not only optimally utilize Doppler wind information from WSR-88D and Terminal Doppler Weather Radar (TDWR) but also take full advantage of rapid and flexible agile-beam scans from the phased array radar at NWRT.

OBJECTIVES

Develop new variational methods to improve the existing radar wind analysis system so it can be applied to any radar scans to produce real-time vector wind displays and monitor data quality. Study radar data quality problems and develop statistically reliable quality control (QC) techniques. Explore new data assimilation techniques to optimally utilize the phased array scan capabilities.

APPROACH

Continue monitoring and recording various QC parameters and related background information (by running the above real-time system). Extract main features exhibited in each type of data quality problems, and find proper QC parameters to quantify the extracted features. Collect independent observations from multiple sources (Dual-Polarization radar, radiosondes, wind profilers and satellites) for "ground truth" verifications of quality problems identified by QC parameters. Use the recorded QC parameter time series and "ground truth" verifications to develop radar data QC techniques.

Apply the modern information theory to problems in designing optimal scan strategies for the phased array radar at NWRT with a given data assimilation system. Use this information-based approach to enhance the integrated approach in combining radar data quality control, error covariance estimation and radar data assimilation. Upgrade the existing 3.5-dimensional variational (3.5dVar) radar data assimilation technique, and explore possible combinations with the ensemble Kalman filter technique.

The PI, Dr. Qin Xu, is responsible to derive basic formalisms and technical guidelines for the implementations. The data collections and QC algorithm developments are performed by project-supported research scientists at CIMMS, the University of Oklahoma. Collaborations between this project and the development of the NWRT phased array radar is coordinated by Douglas Forsyth, Chief of NSSL's Radar Research and Development Division. Dr. Alan Q. Zhao at NRL Monterey and

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Dr. David Parrish at NOAA/NCEP (and their colleagues) perform pre-operational tests as the radar data QC algorithms and assimilation packages are developed and delivered.

WORK COMPLETED

The recently derived cross-correlation function between the radial and tangential velocities (with respect to the direction of radar beam) was combined with the radial-velocity auto-correlation function to improve the radar vector wind analysis based on the statistical (optimal) interpolation technique. Numerical experiments were performed with both simulated radial-velocity observations and real radar observations to test and refine the vector wind analysis technique (Xu et al. 2006a). Experiments were also performed to explore the utility and additional value of the above technique in improving the reference radial-wind analysis for velocity de-aliasing in radar data QC. To identify and remove the interference echoes from sun strobe and other non-meteorological interference echoes, new subroutines were coded to upgrade the version-1 radar data QC package developed in previous years (Liu 2003, 2005; Zhang et al. 2005; Harasti et al. 2005). The effectiveness of the upgraded part of the code is shown in Fig. 1.

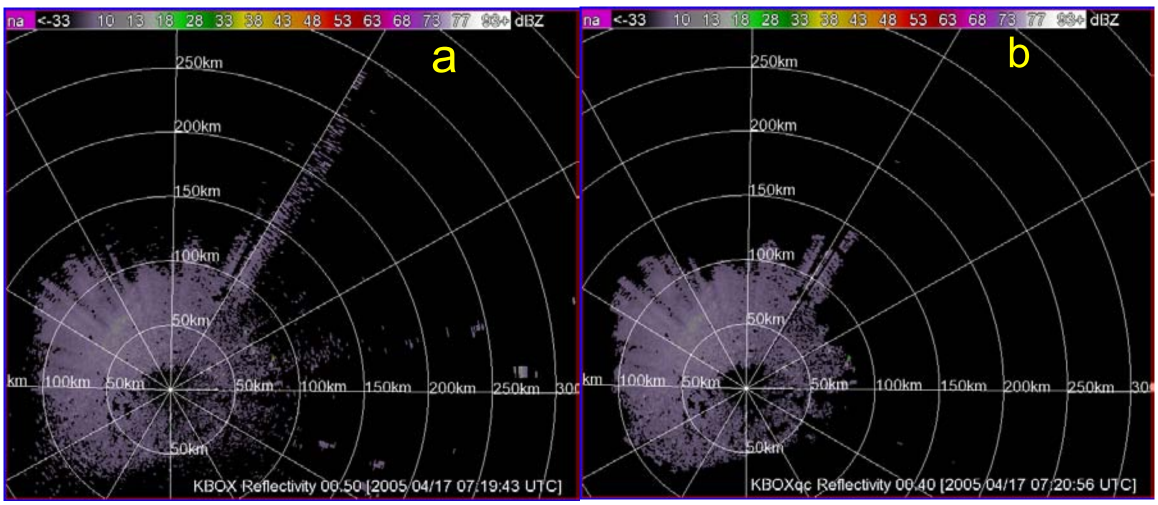

Fig. 1. Reflectivity fields and observed by KBOX radar on 17 April 2005 at 0.5° elevation angle (a) with interference echoes around 32° azimuth angle and (b) after removal of interference and speckle echoes.

By using the non-isotropic form of error covariance function derived for radial-velocity fields on conical surfaces of radar scans, the innovation method (Xu 2003, 2005) was further refined to estimate not only the radar radial-velocity observation error variance but also observation error correlation functions in addition to the background wind error covariance. The refined method was tested with a variety of radar radial-velocity innovation data, including those from the NSSL dual-polarization KOUN radar (Xu et al. 2006b) and phased array radar at the NWRT (Xu et al. 2006c). In the latter case, the time series of radial-velocity innovations were obtained from phased array rapid and the predictions of the Navy's Coupled Ocean/Atmosphere Mesoscale Prediction System (COAMPS, Hodur 1997). Various binning strategies were designed and tested to accelerate the innovation covariance computations and to take the advantages of phased-array rapid and flexible scan capabilities.

Theoretical analysis and assimilation experiments were performed to study (i) how to compress radar observations (obtained with the existing scan strategies) to reduce information redundancy and enhance computational efficiency, and (ii) how to design phased-array scan strategies to enhance radar observation information content for data assimilation. Based on these studies, practical techniques for compressing radar radial-velocity observations into super-observations were developed and coded. The algorithm code was tested with both idealized and real radar data to gain the desired computational efficiency for assimilating observations from multiple radars with the 3.5dVar (Zhao et al. 2005, 2006). The code was delivered to NRL Monterey for further tests and application.

RESULTS

The improved vector wind analysis technique was demonstrated to be as efficient and reliable as expected (Xu et al. 2006a). The technique is being developed with the radar data quality control (QC) package into an automated radar wind retrieval system to produce high-resolution (2 km) vector wind fields for emergency response dispersion models (in collaboration with the Pacific Northwest National Laboratory). An example of the retrieved vector wind field is shown in Fig. 2.

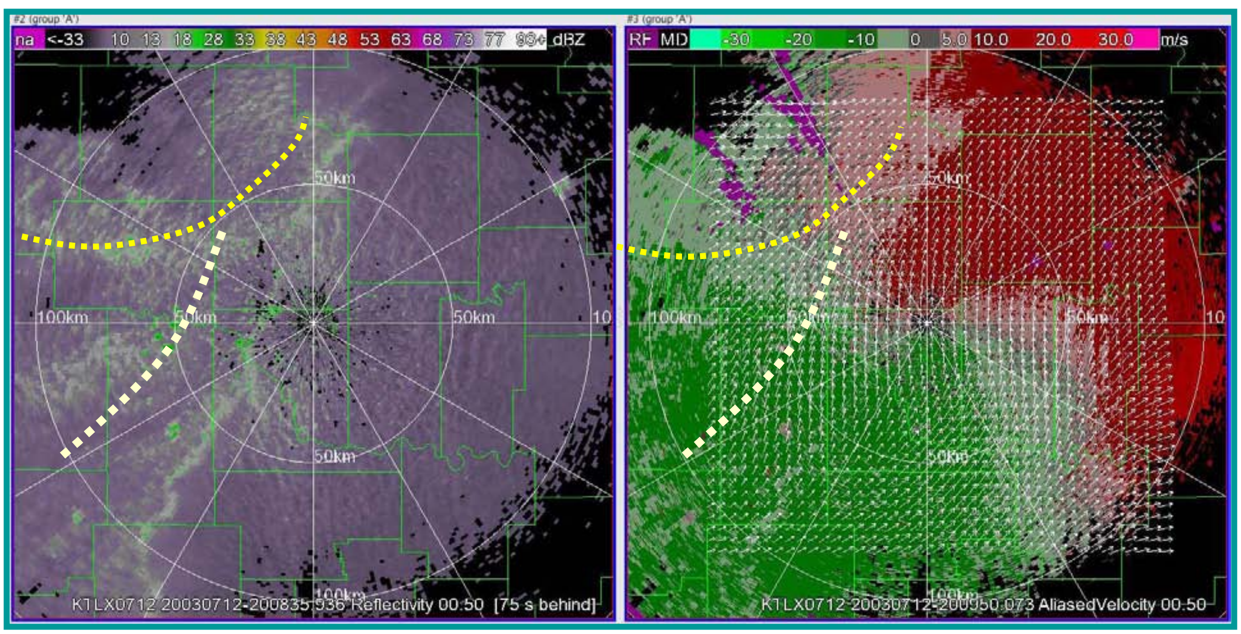

Fig. 2. KTLX observed reflectivity (left panel) and radial-wind (color field, right panel) overlaid with the retrieved wind vectors on 0.5^o elevation at 20:09 UTC on July 12, 2003. The yellow and white dashed lines mark the boundaries of wind shear and convergence.

By using the refined innovation method, the radial-velocity observation error correlation functions were estimated for two cases: (i) phased-array radar observations collected for a squall line on 2 June 2004 (Xu et al. 2006c), and (ii) NSSL KOUN radar observations collected for calm weather on 9 May 2004 (Xu et al 2006b). As shown by Fig. 2 of Xu et al. (2006c), the phased-array radar radial-velocity observation errors are correlated up to r = 3 km, while the KOUN radial-velocity observation errors are correlated only up to 2 km. The differences between the two types of observations can be explained in terms of instrumentation error and sampling error. First, the current phased-array radar (at the

National Weather Radar Testbed in Norman) has less resolution than the KOUN. Limited by the size of the antenna, the phased-array radar beam is wider (about 1.7 degree depending on the viewing angle with respect to the antenna facing direction) than the KOUN beam (about 1 degree). This explains the above differences in terms of instrumentation error. Secondly, the phased-array radar observations were collected for a squall line, while the KOUN observations were collected for calm weather on 9 May 2004, so the above differences could also be partially due to different sampling errors. These results show that radar radial-velocity observation errors are correlated between neighboring range gates and between neighboring beams.

Based on the modern information theory, a singular-value formulation of relative entropy was derived to measure the amount of information extracted from observations by an optimal analysis in terms of the changes in the probability density function (pdf) produced by the analysis with respect to the background pdf (Xu 2006). This formulation can be also used to examine the optimality of radar scanning strategy in terms of maximizing the information content from observations for a given data assimilation system. By using this formulation, theoretical analyses were performed with radar observations and background fields sampled along selected radar beams. The results suggest that the operational WSR-88D radar scans may have excessive spatial resolutions (0.25 km in radial range and about 1^{o} in azimuthal) in radial-velocity observations even for a storm-scale data assimilation system with a resolution of $\Delta x = 2$ km. With the phased-array radar, the rapid and flexible agile-beam scans can be configured adaptively to reduce the spatial resolutions and enhance the temporal resolution and/or measurement accuracy. Assimilation experiments were also performed by applying the ensemble Kalman filter to simulated radar data with four different scan modes (see section 3 and Fig. 1 of Xu 2006c) . The numerical results are consistent with the theoretical analyses.

IMPACT/APPLICATIONS

Fulfilling the proposed research objectives will improve our basic knowledge and skills in radar data QC and assimilation, especially concerning how to optimally utilize rapid-scan radar data to improve numerical analyses and predictions of severe storms and other hazardous weather (including chemical-biological warfare environmental conditions). New methods and computational algorithms developed in this project have been and will continue to be delivered to NRL Monterey for operational tests and applications, in connection with another ONR funded project entitled "Real-Time Meteorological Battlespace Characterization in Support of Sea Power 21" led by John Cook at NRL Monterey.

TRANSITIONS

The radar data QC package developed in this project was also made available to NCEP for operational tests and applications. Based on the feedback from NCEP, the code was upgraded several times and delivered to NRL Monterey. A radar data converter was also coded to read the Navy's radar data and delivered to NRL to adapt the QC package to the Navy radar data ingestion system. The newly developed code for compressing radar radial-velocity observations into super-observations was delivered to NRL Monterey for further tests and application.

RELATED PROJECTS

Radar Velocity Data Quality Controls (funded by NOAA/NCEP to NSSL and OU).
Easy-to-Use Interface for Radar Data Quality Control and Error Estimation (funded by NOAA HPCC to NSSL, and completed)

6.2 Shipboard Data Assimilation System/Doppler Radar (funded by ONR to NRL Monterey).

6.2 Data Assimilation for Mesoscale Prediction (base funding BE-435-009 to NRL Monterey).
Error Covariance Estimation and Representation for Mesoscale Data Assimilation (funded by ONR to OU, and completed in FY06).

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